

# Holocene vegetation history of the Riisitunturi fell area in NE Finland, traced by the palynostratigraphy of two disgenic upland lakes

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A palynological study of an upland lake was conducted in NE Finland to assess the timing of post-glacial vegetational phases as accurately as is possible with bulk samples of hard water-free, evenly deposited sediment. The studied lake, Kolmiloukkonen, as a reference site for the Kuusamo region, revealed an age of ca. 10 580 cal. years BP for the beginning of the post-glacial period, ca. 9500–9200 calBP for the appearance of alder, ca. 5700 calBP for spruce by 1% of arboreal pollen, and ca. 3900 calBP for spruce rise. DCA ordination suggested rather stagnant plant communities in the mid-Holocene. Another lake from the mid-Holocene on top of a saddle mire in the oroboreal sparsely wooded heath was of secondary origin. Its sediment types and macrosubfossils showed an uncommon succession from heath forest to mire and finally to a water basin. The age of establishment of nearly open summits could not be pinpointed palynologically, however, some signals suggest a trend towards more open communities nearly 3000 calBP and about a millennium ago.

## Introduction

Biotopes that differ from the general zonal appearance usually provoke a need to find the reason. Such specialties are met in the Kuusamo region (delimited on a botanical and geographical basis) in NE Finland, not only because of its rich flora, but also because of the existence of mires on slopes. Partly to find explanations for these specialties, the vegetation history of the Kuusamo region was studied especially by Vasari (1962), who assessed numerous palynological series from lakes and mires adjusted with macrosubfossil analyses of past local flora. However, later radiometric datings from many sites gave obviously too old ages. Instead, more recent

results are much stabilized into a time frame that fits into the general east Fennoscandian setting (*see* Discussion in Vasari *et al.* 1996b), still leaving a need for further checking.

The strongly inclined mires were the target of an extensive study by Auer (1923), who solved the general post-glacial forest vegetation history and peat stratigraphies of several slope mires in the Kuusamo Uplands. The somewhat regular character of these slope mires made him even regard them as mire complex type. In later studies of regional variation in mire complexes (Ruuhijärvi 1960, Havas 1961), however, slope mires were treated as topographic variants of aapa mires. Much to specify the paludification dynamics of the past, a series of further paleo-

ecological studies (started by Huttunen 1987) in the heart of slope mires, i.e. in the Riisitunturi area, was established to detect past climatic and environmental changes in this hygriely oceanic (in the east-Fennoscandian scale) region near the present ecotone between the northern boreal and oroboreal vegetation zones.

To create a time scale and a background of the environmental changes reflected in past vegetation and flora, a couple of small upland lakes were selected presuming continuous and more or less even sedimentation. As stated by Jacobson and Bradshaw (1981), a combination of site types in a single study most fully exploits the information contained in sediments. The deposits of these basins were believed to give reliable dating results, being on non-carbonate bedrock.

In this study, I focus on establishing the forest vegetation history of the climatically particular area through pollen analysis of sediments from a lake, which traps mainly regional pollen rain. This site (Lake Kolmiloukkonen) inside the northern boreal forest zone, in addition to forming material for comparison for other studies in the Riisitunturi area, already represents the reference site of the Kuusamo region (type-region SF-i, Vasari *et al.* 1996a) based on previous research (Huttunen 1987). An additional purpose was to study the local vegetation history of another small lake (Riisinlampi), which gathers relatively local pollen. Situated optimally above the forest line, it was expected to give a detailed view of the sensitive ecotone dynamics of the past — the formation of forestless oroboreal heath vegetation. Also, a set of datings should establish a chronology to see how the history of the studied area, with its own climatic and vegetational character, fits into the general frames in Fennoscandia.

## Study area

### Water basins

The studied water basins are inside the Riisitunturi National Park in the parish of Posio, on the Maanselkä watershed between the Gulf of Bothnia and the White Sea (Fig. 1). The Riisitunturi area forms uplands between the lake systems

of Kitkajärvi and Suolijärvi, rising some 200 meters above these large waters. The studied sites are near the felltops of Riisitunturi and Nuolivaara, which are separated by the Riisi valley perpendicular to the orientation of bottom moraine formations. Striae (335° and 295°) are visible in the naked bedrock, the latter coinciding with the observed orientation of nearby drumlins and the direction of the glacial ice flow (Aario *et al.* 1974). Both fells consist of nutrient-poor bedrock, formed mainly of serisite quartzite (Kalliomäki 1985).

Lake Kolmiloukkonen (66°14'N, 28°29'E, 341.1 m a.s.l., by national grid 73500, 35667) is small in size (200 × 110 m), rather shallow (2 to 3 m), with small inlets and outlets in a mire basin (Fig. 1). Riisinlampi (a pond without a name on the map, 66°13'N, 28°33'E, 429.5 m a.s.l., by nat. grid 73492:35703) is still smaller (66 m × 15 m) and shallower (≤ 1 m), with no inlets or outlets on the top of a narrow saddle-formed slope mire in a bedrock furrow between the Riisitunturi felltops.

Because of its larger size and the streamlet entering the basin, Lake Kolmiloukkonen is likely to represent a more regional pollen source than Riisinlampi, as outlined by Jacobson and Bradshaw (1981). Lake Kolmiloukkonen should thus represent a site near the level of a biological province, while Riisinlampi with its very small catchment area forms a kind of pollen trap site for a more local habitat, now an oroboreal heath.

## Climate

Because of the palynological type-region reference status of the site, a rather long list of climatological parameters is given (Table 1). Additionally, the difference between precipitation and evaporation (measured in cultivated areas from the disappearance of snow to the end of July, Alalammi 1987) is about +60 mm, contrasting with about −20 mm on the coastland of the Gulf of Bothnia, only some 150 km SW of the study area. The humidity index (*see* Ruuhijärvi 1960), as an essential climatological parameter related to slope mire formation, also shows clearly high values for the Riisitunturi region.

During a two-month measuring period in

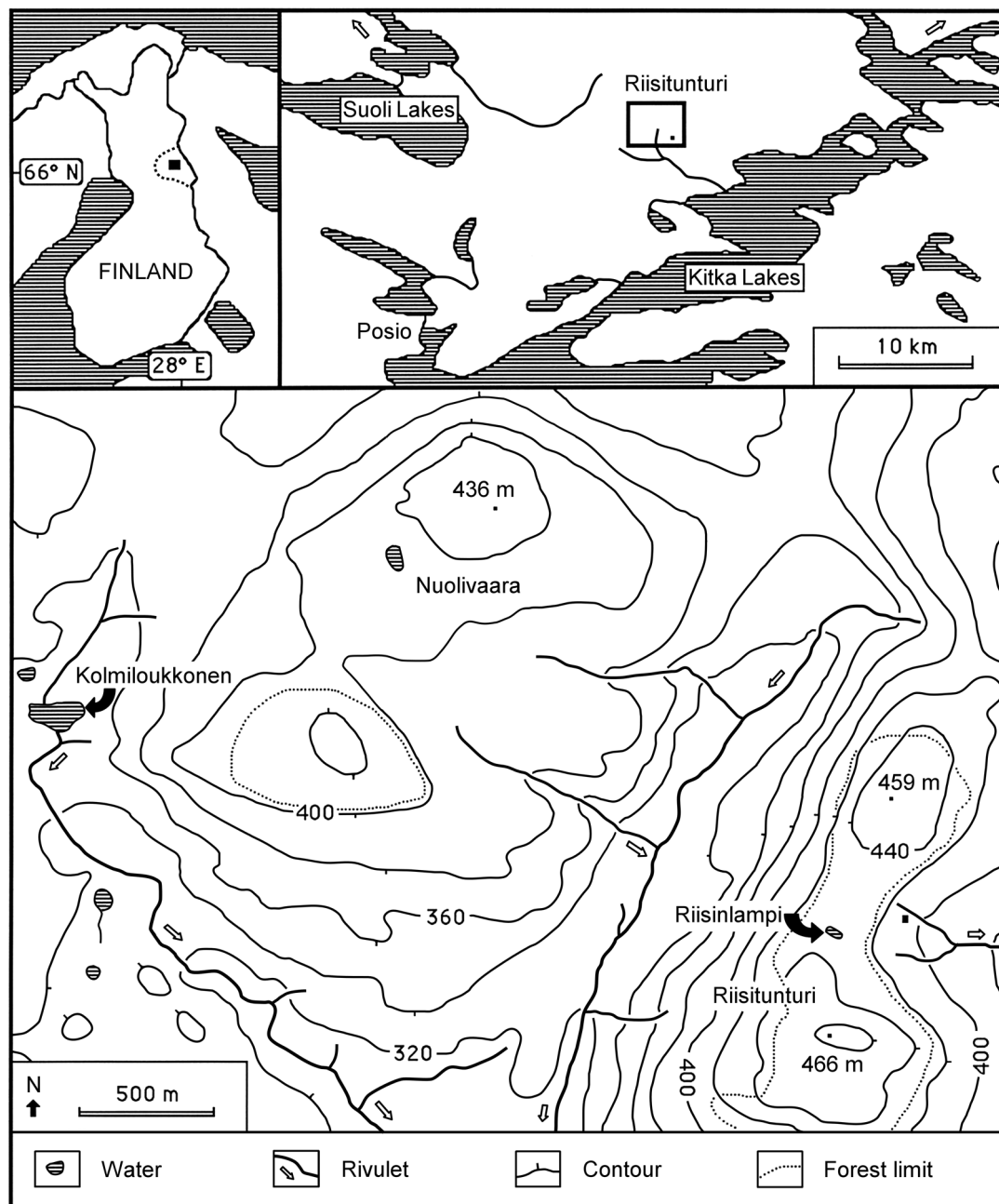


Fig. 1. The study sites Lake Kolmiloukkonen and Riisinlampi. The Kuusamo region delineated by a dashed line.

mid-summer 1979, the daily mean temperatures on the northern top of Riisitunturi were about 1–1.5 °C lower than in the nearby Kuusamo centre, situated about 200 m lower at a distance of about 40 km (Paasovaara 1986). According to the slow sugar inversion method (Ohenoja and Pohjola 1981) used, the mean annual temperature of

the topsoil at the northern summit was –3.3 °C during three measuring periods in 1981–1985 (see also Eurola & Viramo 1986). These measurements confirmed that the adiabatic decrease in mean annual temperature is 0.34 °C over 100 metres, from a forest stand at the northern Kitka lakes (260 m a.s.l.) up to the northern top of

Riisitunturi (458.7 m a.s.l.).

The climate in the Riisitunturi area has been identified as a summit type (Eurola and Viramo 1986). An abundance of e.g. *Calluna*, *Racomitrium lanuginosum*, a thick layer of humus and a heavy crown snow load (*tykky*) all indicate a hygric oceanic climate. In short, the climatologic and biotic evidence shows that the whole area is characterized by a thermally continental, but hygrically oceanic climate, which evidently favours paludification processes even on slopes.

## Vegetation overview

Mesic and submesic coniferous forests dominated by Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) often mixed with Downy birch (*Betula pubescens*) prevail on the moraine landscape at the study area in general. These forests, typical of the northern boreal vegetation zone, get thinner towards the forest line. The forest line in the Riisitunturi fell area lies between 405–451 m a.s.l. (Mikkonen–Keränen 1986), following the average upper limit (400–450 m a.s.l., Haapasaari 1988) of the northern boreal/oroboreal forests (orohemiarctic zone) generally found in the Kuusamo region. The tree line is not reached in the area.

Although the tops of Riisitunturi and its neighboring crowns are nearly bare, they still resemble boreal forests more than alpine vegetation (Eurola and Viramo 1986). The vascular flora of the area is quite poor (Vasari 1986), like also the subalpine flora, which consists of only four taxa: *Arctostaphylos alpina*, *Diphysastrum alpinum*, *Juncus trifidus* and *Loiseleuria procumbens* (Eurola and Huttunen 1984). *Betula pubescens* ssp. *czerepanowii*, instead, must be regarded as a northern boreal taxon. The typical vegetation site type of the summits above the forest line is *Calluna–Empetrum–Vaccinium* type (Mikkonen–Keränen 1986), or as presented by Haapasaari (1988), northern boreal *Calluna–Bryophyta–Lichenes* type. There is no clear difference between the vegetation and organic deposit of the summit heaths vs. thin-peated hummock-level mires, as Haapasaari (1988) stated: “[...] the *Calluna* heaths often approach true swampy communities. This is seen in their floristic composition, i.e. in the presence of a few hydrophilous plant species favoring paludified habitats [...]”.

## Vegetation at the studied water basins

Lake Kolmiloukkonen is in the middle of an aapa mire inside mainly mesic heath forests. By visual

**Table 1.** Climatological parameters for the Riisitunturi area. Estimations are from the map results in Atlas of Finland (1931–1960, Alalammi 1987).

Climatological parameter	Value
Mean annual temperature	ca. +0 °C
Mean temperature in July	ca. +15 °C
Amplitude of monthly temperature means	27 °C
Duration of the growing season	ca. 130 days
Effective temperature sum (ETS, > 5 °C)	ca. 800 °C
ETS at the Riisitunturi fells	ca. 700 °C
Annual mean cloudiness	70%–75%
Average annual mean relative humidity (RH)	ca. 80%
RH in October–December	ca. 90%
Mean annual precipitation	600–650 mm
Number of days in a year with precipitation ≥ 0.1 mm	> 180 days
corresponding value for ≥ 1 mm	ca. 110 days
Snow depth in March	> 70 cm
Max. snow depth in the forests	ca. 85 cm
Duration of snow cover	ca. 200 days
Dominant wind direction (in all seasons)	ca. westerly

observation the tree layer in the surrounding forests consists of spruce (60%), pine (35%), and birch (5%). The dysoligotrophic water of Lake Kolmiloukkonen contains no visible macrophyte vegetation, as was the case also decades earlier (Vasari 1962). According to the macrosubfossil study by Vasari (1962: site XIV), a shore core of Lake Kolmiloukkonen indicated that the past macrophyte shore flora up to the later part of the Holocene has been of higher trophic, containing mesotrophic species like *Cicuta virosa*, *Ranunculus repens* and *Hippuris vulgaris*.

The lake is surrounded by open mire vegetation, with a swamp fen nearest to the shore. To the south of the lake a sedge herb swamp prevails, and in this part only slight signs of the ancient flowing water meadow culture (Vasari and Väänänen 1986) can still be seen (Huttunen 1986). Generally, the mire vegetation in the valley consists of open poor flark fens with low strings, which are replaced by spruce–pine mire site types near the margin.

Riisinlampi lies inside a sparsely wooded oroboreal heath; the nearby vegetation on mineral ground consists of *Calluna–Empetrum–Myrtillus* type of heath (Mikkonen-Keränen 1986). The scarce vegetation in the Riisinlampi area is poor, consisting of *Carex lasiocarpa*, *C. rostrata*, *Sparganium* cf. *hyperboreum*, *Eriophorum angustifolium*, *Menyanthes trifoliata* and *Sphagnum majus*. The pond is surrounded by a narrow belt of mire vegetation, mainly mesoeutrophic ordinary fen and oligotrophic *Sphagnum papillosum* low-sedge fen. The mire complex itself continues to the northwest and southeast, forming a clear and narrow saddle.

## Methods

### Stratigraphy and sampling

The topographies of the sites were levelled at least at the coring points, and the stratigraphy was exposed with a swing corer ("Russian peat sampler"), at 20 m intervals in the basin of Lake Kolmiloukkonen. The peat stratigraphies were described using mainly the plant group which formed the deposit, i.e. the genetic von Post (1922) system. A modified piston corer (Ø 57

mm) was used to collect samples for microfossil analyses from lake sediments at about the centres of the water basins.

### Macrofossil analyses

Because the deposit of Lake Kolmiloukkonen was homogenous fine detritus without any obvious plant remains, macrosubfossils were analysed only from Riisinlampi. The sample volume was 50 ml and 2 cm in height in the continuous sequence. I used a sieving device of 125 µm mesh size to separate seeds and vegetative plant remains after KOH treatment. The nomenclature of vascular plants follows that of Hämet-Ahti *et al.* (1998), and Ulvinen *et al.* (2002) for mosses. Identifications were confirmed with the reference collection in the Department of Biology at the University of Oulu and the author's collection.

### Pollen analyses

One-ml samples were prepared for pollen counting with the KOH and acetolysis procedure, and if the mineral content was inconveniently high, also by using cold dilute HF treatment (Faegri and Iversen 1989). For Lake Kolmiloukkonen, the mean counted total land pollen grains per 78 spectra at 5-cm intervals was 640 (range 265–1246), while the corresponding value for Riisinlampi was 813 (607–1441) grains per 18 spectra at one or two cm intervals. Determination was performed with a Leitz Ortholux microscope and a 40× objective, and in critical cases an oil immersion objective (100× with a numerical aperture of 1.35) was used.

The results of the palynomorph counts are presented as percentages based on the sums of total land pollen (TLP), and the proportions of other groups, based on TLP + n. *Pediastrum* algae were identified at the genus level and recorded as one colony. The results of counting are grouped into a diagram pair in the following order: trees, shrubs, dwarf shrubs, herbs including indicators of more or less human impact (see Huttunen 1980), and at the end, pteridophytes, mosses, aquatics and algae. Construction of a pollen accumulation rate (PAR, a biotope-related

parameter comparable with actual reference measurements, *see* Hicks 2001) was based on  $^{14}\text{C}$  datings and the method of the known sum of additional exotic particles (Stockmarr 1971); only selected taxa are presented. The terminology for palynomorphs follows that of Faegri and Iversen (1989) with the following exceptions: ferns (Pteropsida p.p.) are 'traditionally' called Polypodiaceae, and *Potentilla* spp. also includes *Comarum palustre*. A visually made division of the pollen diagram into local pollen assemblage zones and subzones (PAZ) was based on changes in relative shares.

Detrended correspondence analysis (DCA, Canoco 3.1 for Macintosh) was used as an ordination method to summarize directions of variation in the data set of Lake Kolmiloukkonen and to reveal relationships between ecological assemblages by positioning similar pollen species and stratigraphic samples close together along the DCA axes (Hill and Gauch 1980). Both pollen species and sample data were treated here using DCA (ter Braak 1987–1992), excluding less frequent species. No data transformation was done. As paleoecological data are highly multidimensional, this reduction in dimensionality greatly aids in the correlation of sample levels and in the interpretation of species turnover and the underlying environmental change.

## Chronology

The chronology of the core from Lake Kolmiloukkonen is based on five radiocarbon datings of bulk samples (due to a lack of suitable terrestrial macrosubfossils for AMS dating to determine especially the precise ages of the basal deposit) in the Dating Laboratory of the University of Helsinki. The radiocarbon dating results are presented as years before AD 1950, and the conventional Libby's value of 5568 ( $\pm 30$ ) years was used for the half life ( $T_{1/2}$ ) of  $^{14}\text{C}$ . Calibrated ages were achieved with the CalPal2005\_SFCP programme package (quickcal2005 1.4, Weninger *et al.* 2005). The ages are presented either in calibrated years BP (calBP, given in parentheses if calibrated by the author from older papers) or, for easier comparison with previous studies, in conventional  $^{14}\text{C}$  years before 1950 (convBP).

Because of the even sedimentation and characteristics of the deposit, interpolated ages between linking dates are also suggested.

## Results

### Lake Kolmiloukkonen

#### Sediment stratigraphy

Limnogenic sediments (homogenous fine detritus with a loss of ignition of generally 25% to 35% DW (dry weight), and silty to sandy gyttja, loss of ignition 7.3% DW at the coring point) on basal sandy till in the basin of Lake Kolmiloukkonen show that the body of water formerly covered a major part of it (Fig. 2). Unless there is no hiatus in the sequences now covered by the mire vegetation, the succession began with plant communities that formed Bryales–*Carex* peat mixed with *Equisetum*, to be replaced upwards mainly by more pure Bryales–*Carex* peat. Closer to the surface it changes gradually to *Sphagnum*–*Carex* and *Carex*–*Sphagnum* peats, which are also produced by the present plant communities. The peats were moderately humified ( $H_4$ – $H_6$ ) in general.

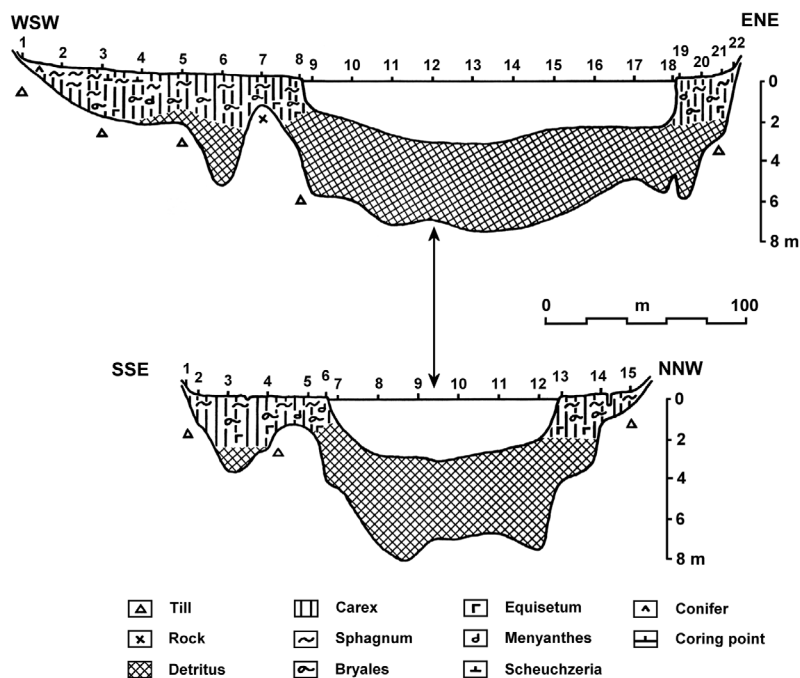
At the sampling site near the centre of the lake the following stratigraphy was discovered: beneath the water column (310 cm), fine detritus (375 cm) and silty/sandy gyttja (10 cm) were on a sandy bottom, all with gradual transitions. The pH values measured from the sediment core from Lake Kolmiloukkonen increased from 5.3 at the top of the sediment to 5.8–6.0 at 60 cm downwards, and remained within this range to the bottom of the column. These moderate reaction values together with the bedrock data (Kalliomäki 1985) evidently exclude the possibility of the hard water effect (Donner *et al.* 1971).

#### Chronostratigraphy and sedimentation rate

The organic deposit of Lake Kolmiloukkonen started to accumulate at least  $9310 \pm 180$  conventional  $^{14}\text{C}$  years ago (convBP, Table 2).

The sedimentation rate in Lake Kolmiloukkonen averages to  $0.35 \text{ mm cal yr}^{-1}$ , being rather even, with only the topmost metre having a





**Fig. 2.** Stratigraphy of the basin of Lake Kolmiloukkonen. The arrow indicate the crossing of the transects and the sampling site.

smaller rate,  $0.24 \text{ mm cal yr}^{-1}$  (Fig. 3). The mean rate thus indicates that each sample represents 29 years, on average.

### Pollen stratigraphy

In the basal part of the core of Lake Kolmiloukkonen, the total annual PAR of the selected main taxa was only about 1000 to 2000 grains  $\text{cm}^{-2}$  (Fig. 4). The PAR was at its maximum around 9000 to 4500 calBP/~8000 to 4000 convBP, with values that were generally 6000–9000 grains  $\text{cm}^{-2} \text{ yr}^{-1}$ , which gradually lowered to the current order of about 2000 grains  $\text{cm}^{-2} \text{ yr}^{-1}$ .

The stratification of pollen grains presented in the form of a relative diagram (Fig. 5) can be shaped into the form of more or less uniform, visually discerned subsets, i.e. local pollen assemblage zones (PAZ).

**KLL 1, *Betula* PAZ** (ca. 9310–8400 convBP/10 580–9350 calBP). The big proportion of birch pollen (ca. 60%–80% of the land pollen sum) characterizes this biozone together with the considerable presence of sedges, graminoids, *Artemisia* and *Equisetum*. The upper transition boundary of the zone is marked by a decrease in birch, an increase in pine and the appearance of alder. The PAR values reveal that the pollen production of all vegetation groups was small in this

**Table 2.** Radiocarbon dates with standard errors from Lake Kolmiloukkonen.  $T_{1/2} = 5568$  years. Calibrated ages according to Weninger *et al.* (2005).

Laboratory number	Depth (cm)	$^{14}\text{C}$ age (conv yr BP)	Calendric age (cal yr BP)	68% range (cal yr BP)	Calendric age (cal yr BC)
Hel-1949	90–105	$3620 \pm 140$	$3951 \pm 194$	3757–4145	$2001 \pm 194$
Hel-1950	165–180	$5330 \pm 180$	$6103 \pm 182$	5921–6285	$4153 \pm 182$
Hel-1951	250–265	$7220 \pm 160$	$8053 \pm 161$	7891–8214	$6103 \pm 161$
Hel-1952	320–335	$8400 \pm 140$	$9346 \pm 156$	9190–9502	$7396 \pm 156$
Hel-1953	365–385	$9310 \pm 180$	$10582 \pm 261$	10321–10843	$8632 \pm 261$

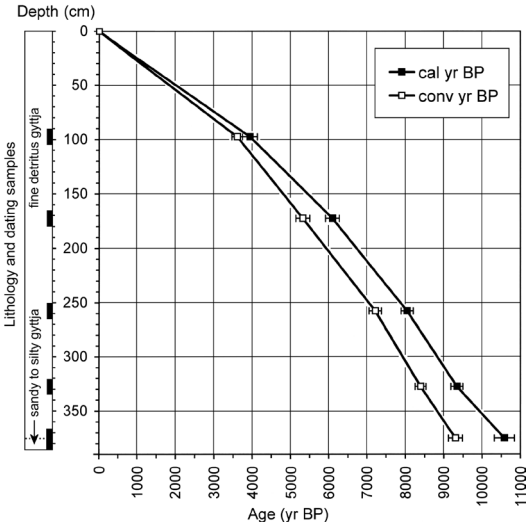


Fig. 3. The age-depth model of Lake Kolmiloukkonen with error bars representing 68% confidence intervals.

phase, and the dominant role of birch was really a relative one based on its annual PAR of around 1000 grains  $\text{cm}^{-2}$ .

**KLL 2, *Pinus*–*Betula* PAZ.** Alder appeared in the pollen flora at  $8400 \pm 140$  convBP/9350 calBP at the transition when the dominance of birch turned to pine; this age thus dates the zone boundary from KLL 1 to KLL 2. At the same level pine exceeds the given PAR threshold (1500 grains  $\text{cm}^{-2} \text{yr}^{-1}$ , Hicks 2001) of the presence of forest, although its percentage proportions were high even before. A subdivision can be made into KLL 2a, *Pinus*–*Alnus* PAZ (ca. 8400–7220 convBP/9350–8050 calBP), where pine pollen exceeds the proportion of birch pollen, contrary to KLL 2b, *Betula*–*Alnus* PAZ (ca. 7220–4950 convBP/8050–5700 calBP). During the KLL2b phase the PAR of birch was around 4000 grains

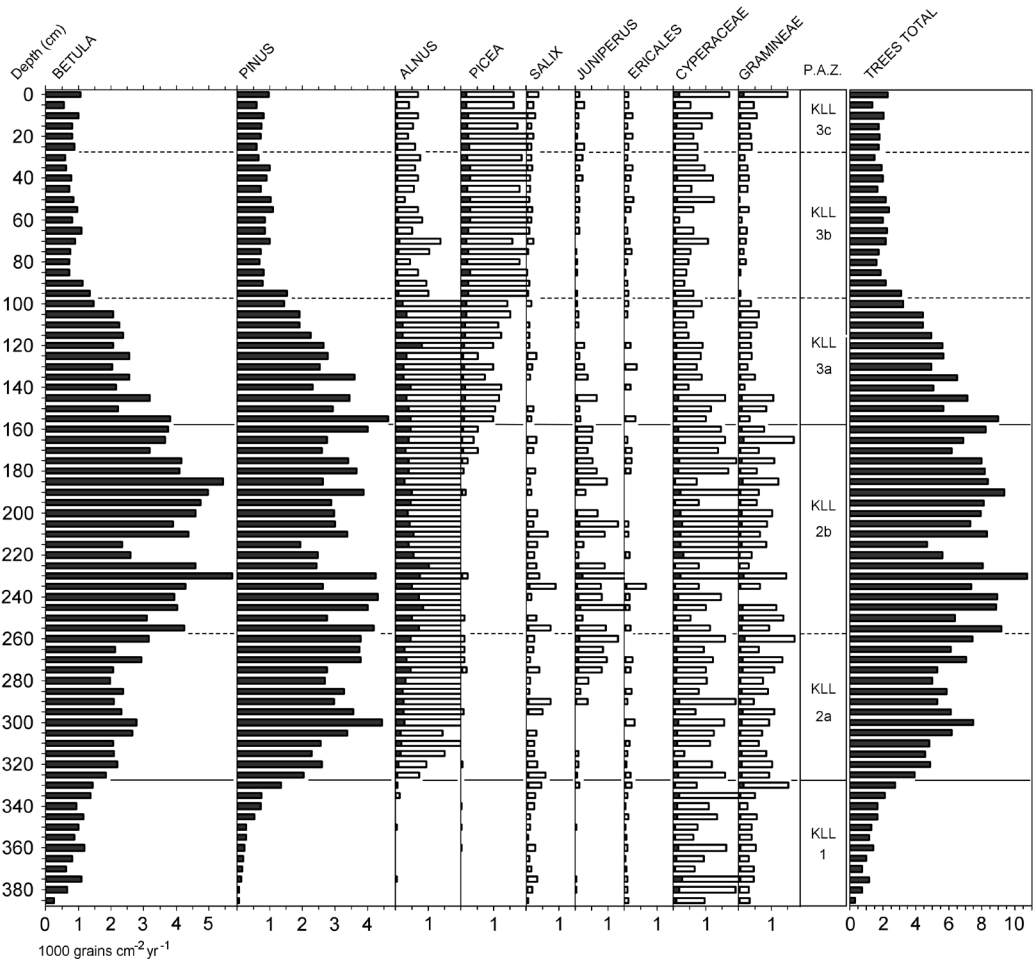
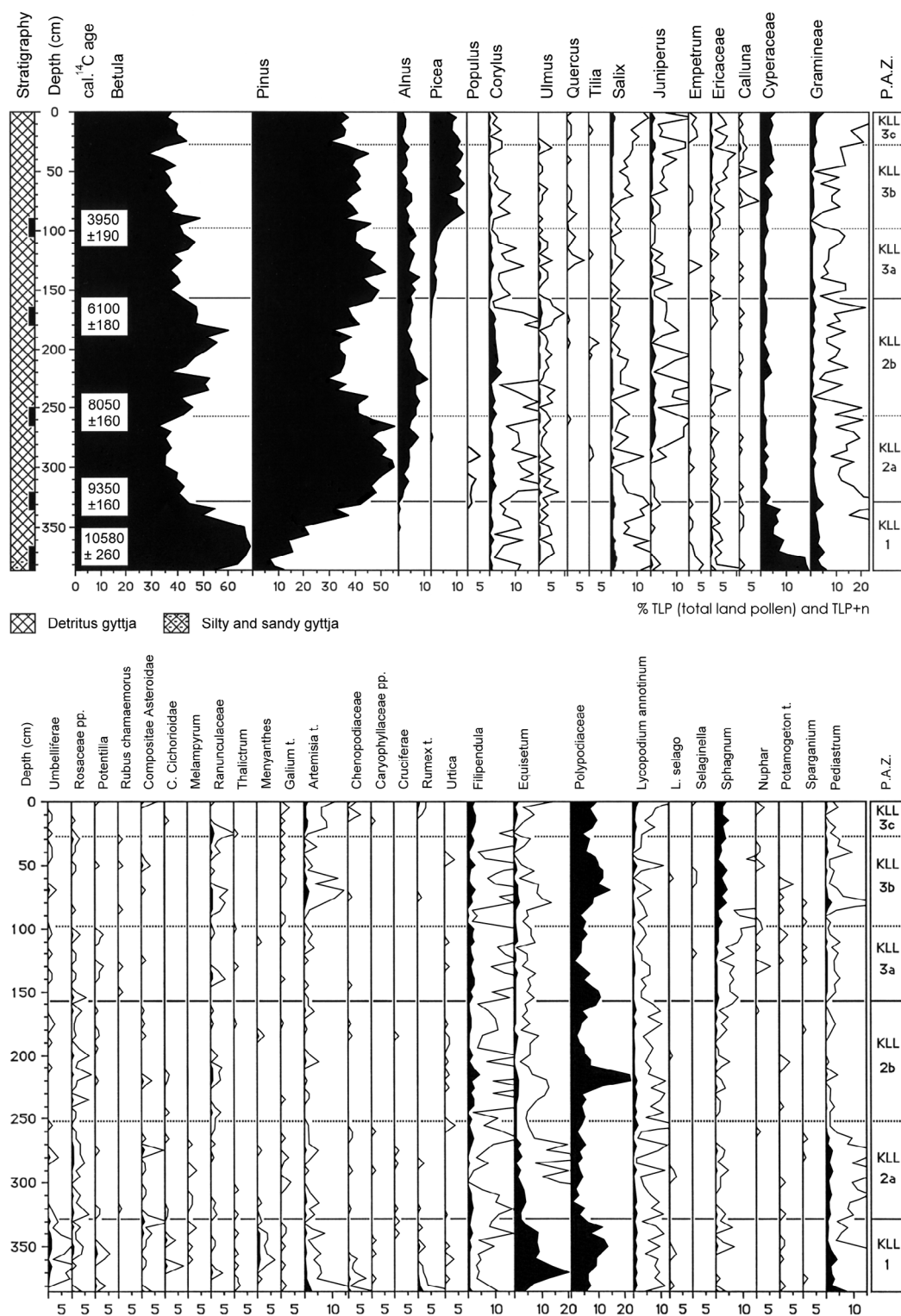
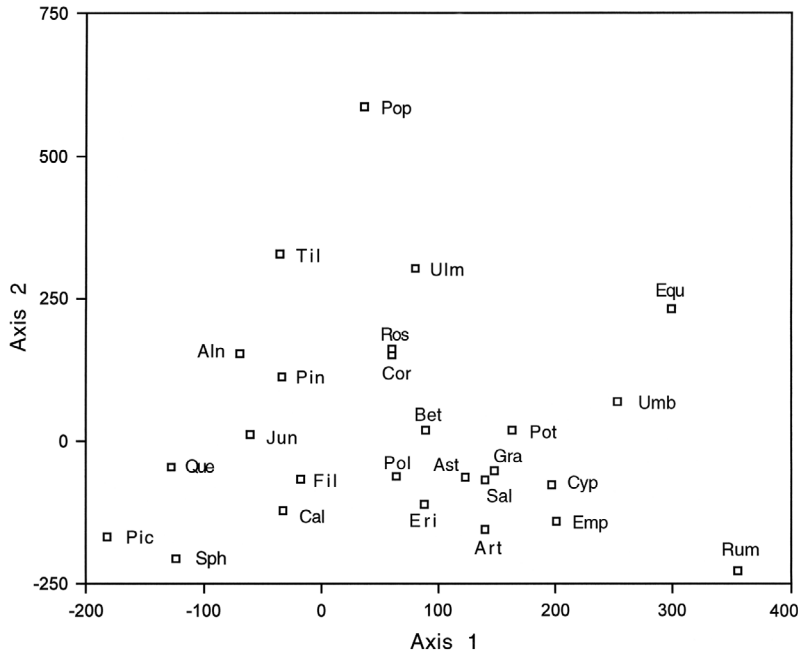


Fig. 4. Pollen accumulation rate of selected taxa in Lake Kolmiloukkonen. The white bars are exaggerated tenfold.





**Fig. 5.** Relative pollen diagram of Lake Kolmiloukkonen. The white curves are exaggerated tenfold. The dates are calibrated  $^{14}\text{C}$  years BP, see Table 1 for calibration.



**Fig. 6.** DCA ordination of pollen species of Lake Kolmiloukkonen. The cumulative percentage variance was 50.4 for axes 1 and 2. The Eigenvalue is 0.111 for axis 1 and 0.039 for axis 2. AIn = *Alnus*, Art = *Artemisia* type, Ast = *Compositae Asteroidae*, Bet = *Betula*, Cal = *Calluna*, Cor = *Corylus*, Cyp = *Cyperaceae*, Emp = *Empetrum*, Equ = *Equisetum*, Eri = *Ericaceae*, Fil = *Filipendula*, Gra = *Gramineae*, Jun = *Juniperus*, Pic = *Picea*, Pin = *Pinus*, Pol = *Polypodiaceae*, Pop = *Populus*, Pot = *Potentilla*, Que = *Quercus*, Ros = *Rosaceae* pp., Rum = *Rumex*, Sal = *Salix*, Sph = *Sphagnum*, Til = *Tilia*, Ulm = *Ulmus*, Umb = *Umbelliferae*.

$\text{cm}^{-2} \text{yr}^{-1}$ , and the rate of pine was around 3000 grains  $\text{cm}^{-2} \text{yr}^{-1}$ . The appearance of spruce closes the *Pinus*–*Betula* PAZ. The continuous ‘tail’ of the spruce curve (empirical limit) starts already at 5330 convBP/~6120 calBP. An age of 4950 convBP/~5700 calBP can be interpolated for spruce presence by one pollen percentage.

**KLL 3, *Pinus*–*Picea* PAZ** also includes pine and birch pollen dominance with spruce occurrence and a considerable but decreasing presence of alder. During the expansion of spruce, other trees decreased, as deduced by their relative and accumulated pollen shares. This zone can be subdivided into KLL 3a, KLL 3b and KLL 3c.

**KLL 3a, *Pinus*–*Betula*–*Picea* PAZ** (ca. 4950–3620 convBP/5700–3950 calBP) includes pollen of birch nearly equal to pine, with the proportion of spruce remaining small (1%–5%). The PAR of spruce was generally a bit more than 100 grains  $\text{cm}^{-2} \text{yr}^{-1}$ .

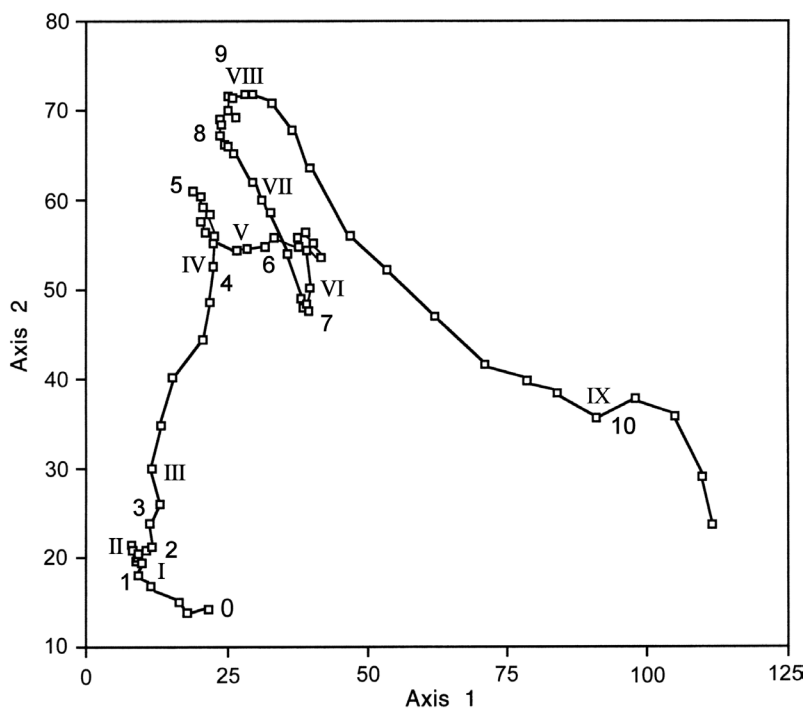
**KLL 3b, *Picea*–*Pinus* PAZ** (ca. 3620–1020 convBP/3950–950 calBP), where the share of pine is again near that of birch, with establish-

ment of spruce to a level of over ten percent, and with an increasing proportion of *Salix*, *Juniperus*, dwarf shrubs and sedges. The PAR of spruce was generally 200 to 300 grains  $\text{cm}^{-2} \text{yr}^{-1}$ .

**KLL 3c, *Picea*–*Betula*–*Pinus* PAZ** (from ca. 1020 convBP/950 calBP onwards), where the section of birch is now bigger than that of pine, while spruce is decreasing but still marked. The share of shrubs, dwarf shrubs and sedges is furthermore considerable, and the proportion of graminoids and *Artemisia* is increased. The values of the pollen accumulation rate in this subrecent zone are near 1000 grains  $\text{cm}^{-2} \text{yr}^{-1}$  for birch, slightly smaller for pine, and near 200 grains  $\text{cm}^{-2} \text{yr}^{-1}$  for spruce.

### Ordination of pollen spectra

DCA grouped the pollen taxa unevenly in the ordination space, although averaging the taxa with bipolar distribution (Fig. 6). The plot of the stratigraphic samples from Lake Kolmilouk-



**Fig. 7.** DCA plot of stratigraphic samples from Lake Kolmiloukkonen as a five-sample running average. Consecutive samples are connected. Roman numerals along the curve are thousands of  $^{14}\text{C}$  years BP, Arabic numerals are in calibrated 1000 years BP.

konen as five sample running averages forms a smoothened temporal sequence (Fig. 7). Consecutive samples or sample groups form kinds of phases of palynological spectra in time, with the projections restricted by the two most significant axes. In their first phases up to a bit over 8000 convBP/9000 calBP they do not form any required homogeneity as assemblages, but a more directional trend. The samples here are slightly directed away from species of (also) a pioneer character, like *Rumex*, *Empetrum* and Cyperaceae. More stable communities existed roughly during the pollen phases KLL2a to KLL3a, i.e. between alder establishment and the increase of spruce at about 8000 to 4000 convBP/~9000 to 4500 calBP.

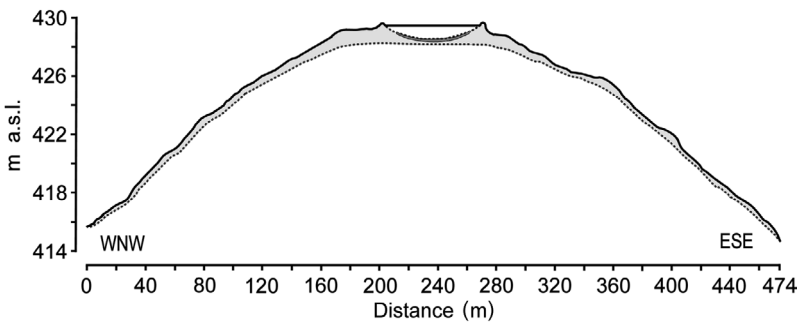
The general trend of the position of the pollen samples from about 4000 convBP/~4500 calBP onwards is towards e.g. *Picea* and *Sphagnum* in species ordination. After a somewhat stable phase at the end of the KLL3b phase during the interpolated ages of 2000 to 1000 convBP and calBP, a turn of events leads in the direction of species of (also) an anthropogenic character, like *Artemisia* and *Rumex*, and of present habitats with e.g. *Empetrum*, *Calluna* and Cyperaceae (Fig. 6).

## Riisinlampi

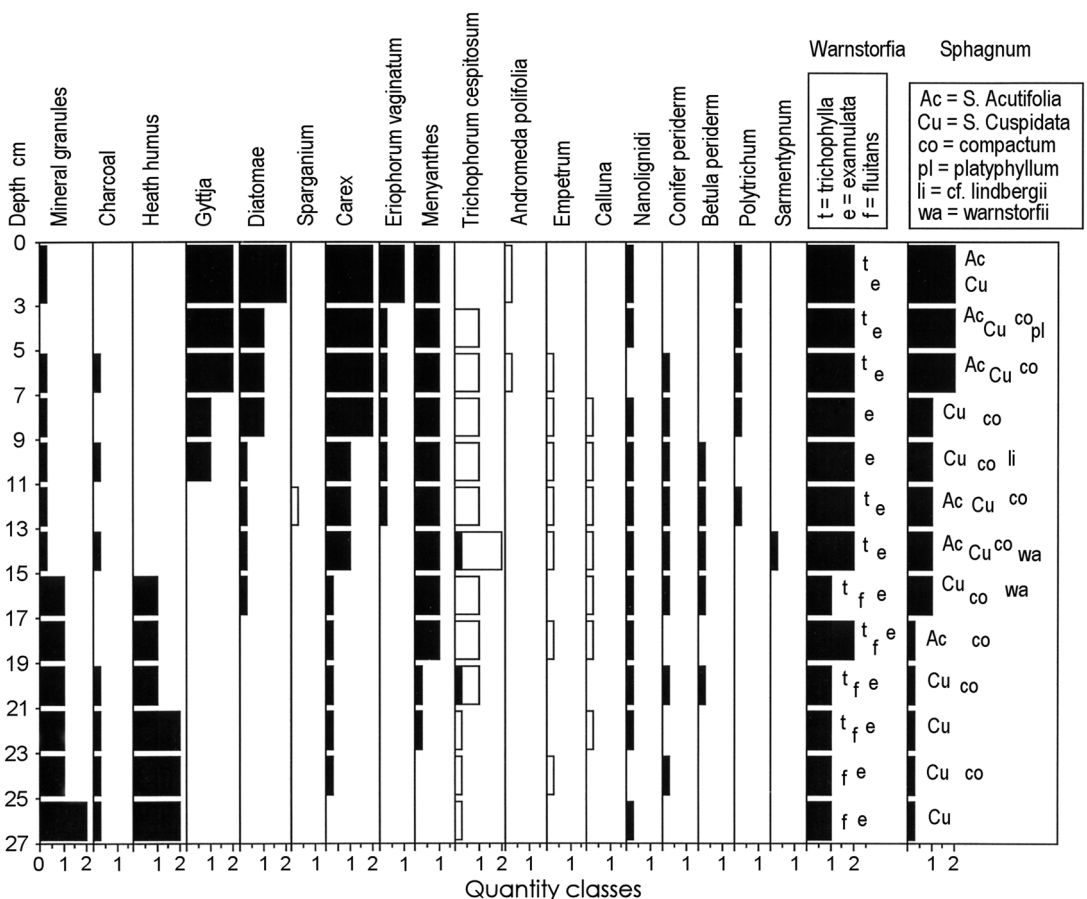
### Sediment and macrosubfossil stratigraphy

Hummock peat banks have dammed the pond on the slope mire saddle top (Fig. 8). The sampling site in the middle of the pond had 27 cm of thick, loose deposit on a till base. Because the sediment consisted of terrestrial and limnic deposits under a very shallow body of water, suggesting various scales in accumulation rate and various characteristics as a pollen trap, the site is probably not ideal for reconstructing the history of oroboreal heaths. However, it was evident that it reveals one path of successional trends of saddle mire tops, and is worth a closer study.

Well-humified heath humus-like peat with mineral granules formed the basal (about 23–27 cm) sedentary organic soil on tight sandy till. A charcoal layer was visible in the organo/minero contact (at 27.0 cm), as well as very thin layers at depths of 25.2, 21.7 and 19.5 cm. The middle column (about 11–23 cm) consisted of *Carex*–*Sphagnum*–Bryales peat, and the top third (0–11 cm) was coarse detritus with remains much of brown and white mosses, sedges and some Diatomophyceae (Fig. 9).



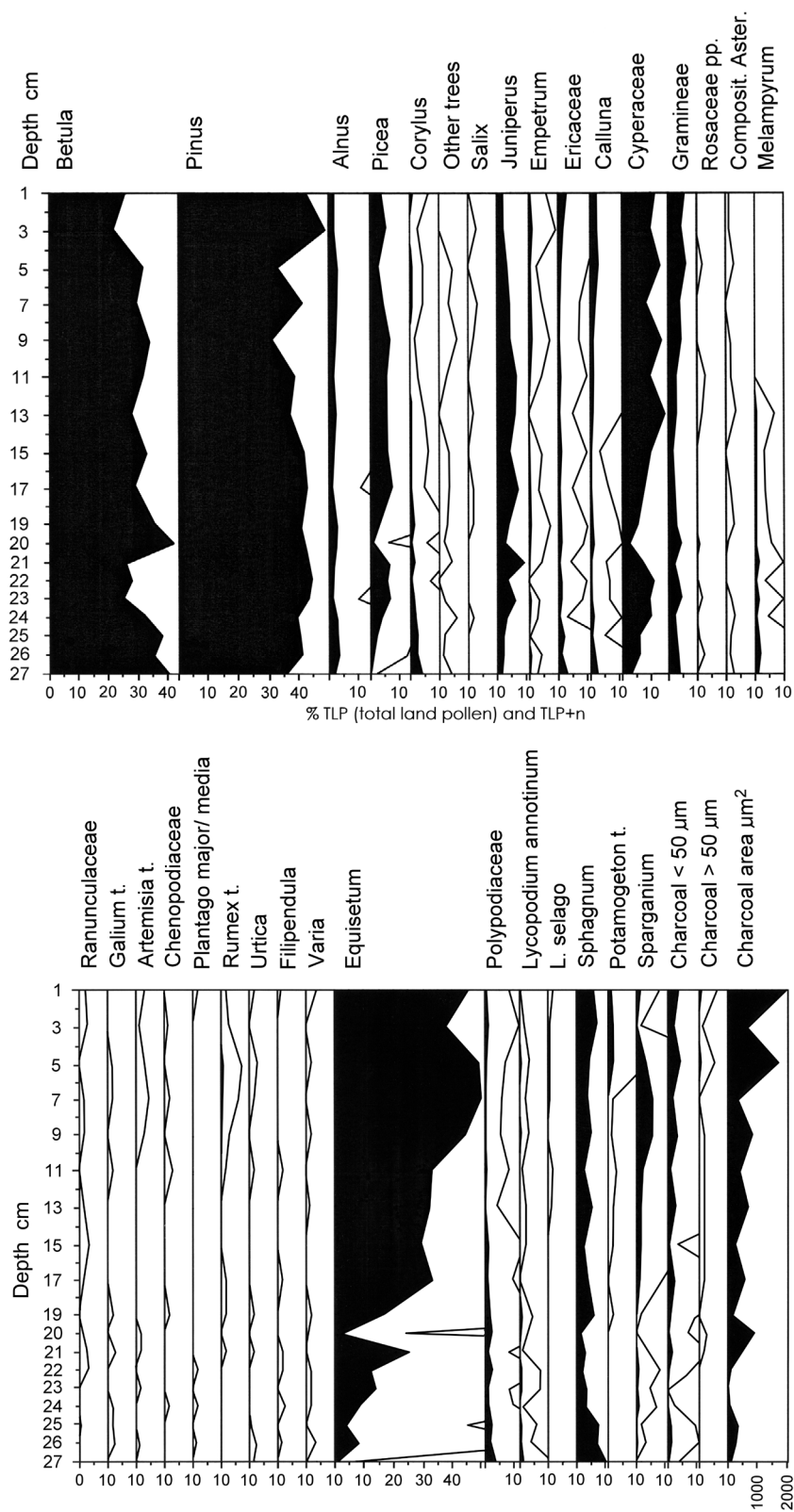
**Fig. 8.** Longitudinal section of the saddle basin of Riisinlampi. The peat layer is presented in grey on thin till and the bedrock.



**Fig. 9.** Macrosubfossil diagram of Riisinlampi. The black bars denote vegetative tissues, the white ones, seeds. The coarse scale is: 1/4 rare, 1 moderate, 2 abundant.

In the basal column, taxa like *Warnstorfia exannulata* and *W. fluitans* with Sphagna of the Cuspidata section show wet conditions in spite of the humus-like main medium. Towards the middle part of the core there appear taxa like *Sparganium* sp., *Warnstorfia sarmentosa*

and *Sphagnum warnstorffii*, indicating watery and also slightly springy (indications according to Eurola and Huttunen 2006) conditions. The remains of *Sphagnum compactum* nearly throughout the sequence suggest a tendency of seasonal drought, at least to some extent.



**Fig. 10.** Pollen percentage diagram of Riisinlampi. The white curves are exaggerated tenfold.



## Pollen stratigraphy

The relative pollen diagram (Fig. 10) shows a rather monotonous palynomorph stratigraphy covering the abiegnic time. Compared with the series from Lake Kolmiloukkonen, this dates roughly to 5500–5000 convBP/~6300–5750 calBP. Based on this assumption, the accumulation of organic matter was very slow, annually about 0.04 to 0.05 mm. Within the pollen sequence, e.g. *Melampyrum* as a forest species decreased, while palynomorphs of *Equisetum*, hydrophytes and charcoal particles increased.

## Discussion

### Forest vegetation history based on pollen from Lake Kolmiloukkonen

Morphometry and the character of sediment with dating results (Figs. 2 and 3) from Lake Kolmiloukkonen suggest calm and continuous accumulation of deposits during the entire post-glacial period, although the small inlet may cause minor pollen in-wash. No hard-water effect giving too old radiometric results could be detected. Thus, the temporal frame for the phases in vegetation dynamics can be regarded as more or less reliable, keeping in mind the restrictions of the bulk samples, however (*see e.g. MacDonald et al. 1991*).

Many of the earlier results of the oldest organic deposits in the region and a bit north have varied within a broad scale, e.g. 8240  $\pm$  190 convBP (~9160  $\pm$  240 calBP) at Kangerjoki (Hicks 1975) to 12 350  $\pm$  400 convBP (~14 740  $\pm$  750 calBP) at Aapalampi (Sorsa 1965). The oldest dating result here, although from a bulk sample 25 cm in height, is 9310  $\pm$  180 convBP/~10 580  $\pm$  260 calBP, which confirms and fits in with the more recent results, especially with the necessary re-investigation of Aapalampi (Vasari *et al.* 1996b), showing that deglaciation of the region was not older than ca. 9500–9000 convBP, calibrated as ca. 10 800–10 100 calBP.

In general, the successive development of forests in the region follows the trends already interpreted and described by various authors

(e.g. Vasari 1962, 1974, Hyvärinen 1972, Hicks 1975), and as a review of event stratigraphies for the region by Vasari *et al.* (1996a). The periglacial pioneer vegetation in the margin between retreating ice and advancing forests was too short in duration and slightly transgressive in time to be properly reflected in pollen studies in this northerly region, contrasting to the situation in SE Finland (Bondestam *et al.* 1994). Based on bulk dating samples, the pollen accumulation rates (Fig. 4) could be utilized with caution to evaluate precisely the first establishment of forests. For pine, however, the date 8400 convBP/9350 calBP for establishment can be obtained. The rapid increase of pine allows timing of its establishment to roughly fit the isochrone map of Huntley and Birks (1983) in the NNW directional spread, although they used already a 25% limit for the spread of pine. Thus, the result fits and augments the general time transgressive pattern of pine expansion (Seppä and Hammarlund 2000) in northern Fennoscandia.

Pine increased its role in thickening birch-dominated forests, until alder appeared at 8400 convBP/~9500–9200 calBP in the forest vegetation (Figs. 4 and 5) that was already at that time dominated by pine. The species composition of trees during the early Holocene was not so much guided by climatic factors, but by differences in the migration abilities of species (e.g. Seppä 1996). Generally, the spread of pine was meta-chronic (Hyvärinen 1972, Vasari 1974, *see also* Seppä 1996), but that of alder more synchronic, however, within the scale of centuries in dating results, e.g. 8880 convBP (~9950 calBP) in Heikkinen and Kurimo (1977) to 8040 convBP (~8950 calBP) in Seppälä and Koutaniemi (1985). Thus, while a pine-dominated phase can be detected before the spread of alder in eastern Finland, these phases were more simultaneous in the Kuusamo region (*see also* Sorsa 1965, Tolonen 1967).

On the Russian side east of the study area, alder seems to rise earlier, at roughly 9000 convBP (~10 100 calBP) as generalised by Jelina (1985), also at ca. 9000 convBP in a foothill lake of Mt. Nuorunen (Huttunen *et al.* 1994) and at a tentative age of 8600 convBP (~9600 calBP) in Paanajärvi (Huttunen *et al.* 1999). These results in a way suggest a westward spread of alder in



the region, thus complementing the rather complex view, based on sparse data on its past rise, expressed by the isopollen maps of Huntley and Birks (1983).

The proportion of spruce in the pollen diagrams proves that the presence of this species has been a long-lasting topic in palynology, and the suggested percentages of its presence have varied over a large scale (*see* Tallantire 1980). This matter is relevant especially in the Kuusamo region, where the spruce curve so many times has “a long tail” (say < 3%). In the material of Vasari (1962), macrosubfossil evidence shows spruce in spectra where its proportion of arboreal pollen was about 1% or even 0%, whereas 5% (Tolonen 1983) or 10% (Tallantire 1980) were presented as valid for showing regional distribution. These latter values seem to be too strict when evaluating the present material and the results of Hicks (1986), which showed less than 10% of modern pollen values for this region with a considerable (35% to 70%) proportion of spruce in its tree coverage.

The review by Giesecke and Bennett (2004) presented spruce as having spread in Fennoscandia in two phases: rapidly in the early Holocene, with low population density giving rise to small outpost populations, and spreading as a front, mainly from ESE to WNW in the mid- to late Holocene, with high population densities. Their opinion on the final expansion of spruce shown by the 5% and 10% values or by the rise of the curve sounds reasonable, while evaluation of the first appearance still remains problematic. As Giesecke and Bennett (2004) summarise several critical problems linked with low spruce pollen shares, it would be reasonable not to speak (only) about empirical or rational spruce pollen limits, but about certain percentage limits. This means expressing the first probable local establishment as e.g. one percent (or any agreed percentage)/AP limit of *Picea*.

In the Lake Kolmiloukkonen profile, the Pc 1%/AP (“Pc1”) limit dates back to ca. 4950 convBP/~5700 calBP, supporting the general setting of Giesecke and Bennett (2004) adapted for the Kuusamo region. The pollen assemblage boundary KLL2/KLL3 delimited by this one percentage basis, with its spruce pollen PAR values (99/105 grains) on the boundary of the

category (50–100 grains) in Hicks (2001): “Species present but only sparsely”, proves for its part the validity of the modern influx method in interpreting past tree immigration.

The clear increase in the proportion and accumulation rate of spruce pollen at the expense of not only alder and birch, as usual, but also of pine, took place at around 3600 convBP/3900 calBP. This powerful increase of spruce may include a proxy climatic signal reflecting a climatic shift to circumstances indicated by spruce, i.e. thermal continentality and especially hygric oceanicity, fitting — by merit of its gradual shift — generally the results from eastern Kuusamo (Sarmaja-Korjonen and Hyvärinen 1999) and northern Fennoscandia (Seppä *et al.* 2002) regarding a past increase in humidity of the climate.

Sphagna as an indicator of past change in hygric conditions, having started to increase already about 5000 convBP/~5750 calBP, strengthened its share with Ericaceae also about 3600 convBP/~3900 calBP, to be followed by taxa of more open habitats like willow, juniper, heather and sedge-like plants. Among increased dwarf shrubs, *Calluna*, an important indicator of forest line (Hicks 1986) and coastal heaths (Kaland 1986), must be noticed as a probable pointer of establishment of oroboreal heathlands. By interpolation this change dates back to ca. 2800 convBP/2950 calBP, coinciding with the results of Kultti *et al.* (2006) regarding the time of tree line withdrawal in Lapland.

The marked increase of *Artemisia* simultaneously with the above-mentioned taxa can be explained by the long-distance transport of pollen being more easily represented in relative presentation in opening landscape during the last millennia. No reliable palynological evidence of “slash-and-burn” cultivation, which has been rather extensive in parts of Kuusamo, or of flooded wetlands (Vasari and Väänänen 1986), can be traced in the data of Lake Kolmiloukkonen.

The overall pollen accumulation rate (Fig. 4) as an indicator of density of tree cover, relating even further to the major latitudinal vegetation zones (*see* Hicks 2001), increased from the periglacial time to about 8000 convBP/9000 calBP and had an “oscillating high plateau” from about 7400 convBP/8200 calBP to about 4950

convBP/5700 calBP at the end of the preabieg-nic time, and rather high values still at 4000 convBP/4500 calBP. In a way, the period of high PAR values can be deduced to represent the optimum phase of the Holocene as revealed by Lake Kolmiloukkonen's profile. Inferred from the PAR results, the fertility of the dominant vegetation decreased from that time until about 3500 convBP/3800 calBP to be levelled down to the current moderate order. Direct conclusions cannot, however, be drawn on the basis of the pollen accumulation rate, because e.g. the dominant conifer changed from pine to spruce, which has a clearly smaller pollen producing ability.

The ordination result of the pollen samples (Fig. 7) gives a view suggesting rapid development, i.e. instability of forest vegetation from the time of deglaciation to somewhat over 8000 convBP/9000 calBP, roughly when pine forests had become established. Similarly, the following communities seem to be more stabile to about the boundary of pollen assemblage zones KLL3a/b, when spruce had clearly established itself as an essential component of forests a bit earlier than 4000 convBP/~4500 calBP. Thus, the most probable climatic optimum of the Holocene can here be seen as a phase of closed and stabile forest vegetation communities, keeping in mind, however, the restriction of the ordination method used. Anyhow, it fits well the general climate reconstructions of boreal regions in Europe (see e.g. Seppä *et al.* 2005). From about 4500 calBP the succession in pollen assemblages was rapid, except for the short stagnation between 2000 and 1000 convBP and calBP. The major change at about 4500 calBP may be a reflection of thinning and/or fragmentation of forests due also to intensified paludification (see e.g. Vasari *et al.* 1996a), and, again supported by DCA, the change during the last millennium is a reflection of the formation or expansion of the oroboreal upland heaths, thus substantiating the opinion of Vasari (1965) concerning their quite recent origin.

When dealing with climate and its consequences on vegetation in the past, emphasis must be placed on the subjection to crustal land uplift during the whole post-glacial period. During the last 7 ka it has still been 70–80 m in the area (Eronen 1974). The forest line has evidently descended to the present-day level due to

simultaneous processes: general climate cooling during the late Holocene, pedogenic impoverishment and glacio-isostatic land upheaval.

## Remarks on the history of Riisinlampi

Riisinlampi, an ideally located site just above the ecotone boundary, appeared to be a water basin of secondary origin, and with its variable sediment it did not form an ideal source as a paleoenvironmental background record. While the destiny of so many water basins is to be more or less temporary between glaciations, Riisinlampi represents an opposite trend. The basal peat on charcoal band with terrestrial plant remains suggest that the saddle top plateau mire was once initiated by paludification after a forest fire, also partly with plants showing supplementary nutrient status and periodic drought. Later peat deposits show a very slight ground water effect, suggesting that it played a role in the formation of this probable mire nucleus. The peat and sapropel deposits show a complex composition of plants, indicating various, even opposite ecological indications in the same layer. This mixture may be a result of regelation disturbance in the shallow basin. The present marginal tight peat banks of the pond display a clear ice-push effect, which evidently keeps the site unaffected by overgrowth processes.

The palynological results of Riisinlampi much repeat the general features gained from Lake Kolmiloukkonen. It is worth noticing, however, especially in the upper part of the diagram, the evident palynological “background noise” in the form of long-distance transport pollen that includes anthropogenic taxa (*Artemisia*, *Chenopodiaceae*, *Rumex*) which do not grow within several kilometres of the study site. The age of this change is unknown, but it is visible in the phase of probable enlargement of the pollen source area near the level where the curve of *Melampyrum* as a forest species ends, to be replaced by species which can be interpreted as more typical of open landscape. The evidently high proportion of long-distance transport pollen at this upland heath site demonstrates that water basin size (Jacobsen & Bradshaw 1981) as such is not a suitable measure for evaluating the origin of pollen — the size of the

opening having the relevant role. The same basic significance of pollen catchment was also pointed out by Seppä (1998) when comparing tundra and boreal forest sites. Past changes e.g. in basin size and vegetation elements in the landscape structure have evidently caused changes in the effective pollen source area (*see* Koff *et al.* 2000, Bunting *et al.* 2004), making estimations of forest line changes complex.

Although Riisinlampi did not form an ideal paleosite because of its young abiegnic age and unknown deposition rate combined with probable disturbances, it forms a special example of the successive destiny of a paludified heath forest site and an opposite successional trait instead of the usual terrestrialisation process forms (*see* Korhola 1995). The same kind of geomorphic event has also been detected in the boreal peatlands of Labrador as an “[...] extreme version of paludification providing a striking contrast to classical concepts of hydrarch succession [...]” (Engström 1984). In a way, Riisinlampi can also be interpreted as a flark pool developed from a flark cross of a mire (Sjörs 1983), or expressed in hydrotopographic typology, from a reservoir basin of an aapa mire complex (Laitinen *et al.* 2005).

## Conclusions

The whole post-glacial depositional history is stored in the quite evenly accumulated sediments of Lake Kolmiloukkonen, and it is not older than ca. 10 600 calBP. Alder appeared in the region at ca. 9500–9200 calBP, and spruce appeared in a one percentage proportion at ca. 5700 calBP, to be more steadily established at ca. 3900 calBP. After that, without any clear juncture, species typical of more open habitats showed an increasing trend. Heather, judged as an indicator of forest line, increased just after 3000 calBP. Furthermore, a change in forest vegetation, as suggested by the ordination of pollen spectra at ca. 4500 calBP, includes a shift from more or less stabile forested communities towards the present rather poor conifer woods, and another change during the last millennium more clearly towards open heath habitats. The event at about 4500 to 4000 calBP has proved to

be somewhat synchronous in boreal Europe, and the last 1000 years represented the coldest period since ca. 9500 calBP, as concluded by Seppä *et al.* (2005). Although the obtained data generally support well the earlier results discussed above, the dating results concerning the establishment of oroboreal heaths must be treated with caution; especially because the actual vegetational reference indicates that the limits of fertile forest to non-flowering forests up to the sparsely wooded heaths are so gradual.

Remains of the few obligatory alpine species, needed to support reconstruction of the establishment of the oroboreal heath, could not be detected in the ideally located Riisinlampi; this is well understandable because of their very restricted distribution and limited identifiable palynological characters. Anyhow, Riisinlampi, by its extraordinary origin when compared with Lake Kolmiloukkonen, stresses local factors as a force causing here physiographic development to a convergent result.

The Holocene crustal land uplift even alone must have had marked consequences on climate and vegetation in the past in this sensitive area of the northern boreal–oroboreal ecotone. The forest line has evidently descended to the present-day level due to simultaneous processes: general climate cooling during the late Holocene, pedogenic impoverishment and glacio-isostatic land upheaval.

The environmental past of Fennoscandia is largely discussed in recent literature, including changes in temperature and hydrology in time frames (*see* Bjune *et al.* 2004, Seppä *et al.* 2005). The results obtained here generally support and fill the paleoecological records on a large spatial scale; however, it must be kept in mind that, in spite of generally similar responses to climate as a driving force, especially part of the past environmental changes in form, strength and synchronicity may vary from site to site (*see* Faegri and Iversen 1989). Not only each bioclimatic region, but every basin in its geographical setting with its own reconstructive capacities has more or less its own history and character as a paleoarchive.

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